Progress and Plans for a US Laser System for LISA

J Camp, K Numata, and M Krainak
NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA

E-mail: jordan.b.camp@nasa.gov

Abstract. A highly stable and robust laser system is a key component of the space-based LISA mission architecture. We describe our progress and plans to demonstrate a TRL 5 LISA laser system at Goddard Space Flight Center by 2020. The laser system includes a low-noise oscillator followed by a power fiber amplifier. The oscillator is a low-mass, compact external cavity laser, consisting of a semiconductor laser coupled to an optical cavity, built by the laser vendor Redfern Integrated Optics. The amplifier is a diode-pumped Yb fiber with 2.5 W output, built at Goddard. We show noise and reliability data for the full laser system, and describe our plans to reach TRL 5.

1. Introduction

The past year has seen the opening of the field of Gravitational Wave Astronomy, due to the LIGO discovery of gravitational radiation from a merging Black Hole Binary system [1]. In addition the results of the LISA Pathfinder mission have shown it is possible to achieve drag-free control at the required LISA levels [2]. These results have re-focused the LISA community on LISA technology development. We report here on the status and plans to provide a TRL 5 LISA laser by 2020.

We are pursuing an all-fiber/waveguide space laser solution based on the MOFA (master oscillator fiber amplifier) configuration, which is a waveguide-based oscillator followed by a preamplifier and a power amplifier (Fig. 1). These components naturally fit into the high precision LISA laser system because of their high mechanical robustness, excellent reliability, compact form factor, and high wall-plug efficiency. Our research has included development of 1064 nm Planar-Waveguide external cavity laser (PW-ECL), PW-ECL reliability tests, and amplifier development, including its noise measurements and reliability studies. For the preamplifier, we are looking into two options, a fiber-based amplifier (as in Fig. 1) and a semiconductor optical amplifier (SOA).

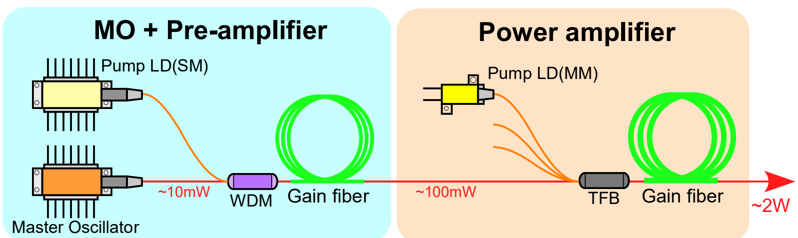

Fig. 1 Concept of the MOFA configuration. Optical isolators, modulators, and redundant LDs are not shown. SM: single-mode; MM: multi-mode

IOP Conf. Series: Journal of Physics: Conf. Series **840** (2017) 012013 doi:10.1088/1742-6596/840/1/012013

2. Master Oscillator

We have developed a fiber ring laser [3] and a fiber DBR laser for space interferometry. Although these lasers perform like the non-planar ring oscillator (NPRO) at low (<10 kHz) frequency, they have a larger relaxation oscillation peak, around 1 MHz, which could affect the heterodyne interferometry typically operated near this frequency. Therefore, we shifted our focus to the development of the planar-waveguide external-cavity diode laser (PW-ECL). The Telecordia-qualified PW-ECL, built by Redfern Integrated Optics (RIO), offers advantages over solid-state lasers, including simpler design, more compact size, lower mass, and less consumption of electrical power. The narrow reflection peak of the Bragg reflector in the planar lightwave circuit (PLC) enables stable, low-noise, single-mode lasing at a selected wavelength. The design may be modified to support a 1 GHz bandwidth, integrated intra-cavity phase modulator [4]. Originally, the PW-ECL was only available at the telecom C-band (1550 nm); based on experience with this product, RIO has successfully built 1064 nm version of PW-ECL by changing the gain chip and the PLC design. Maximum output power of PW-ECL is 15 mW.

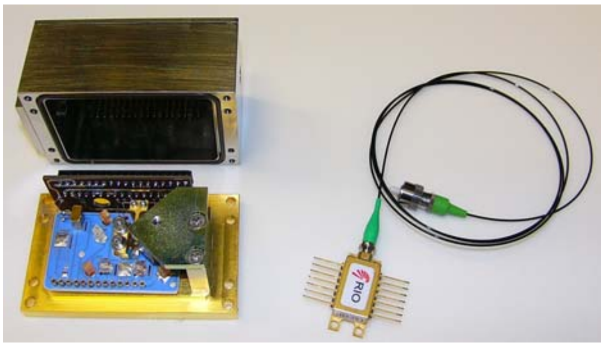

Fig. 2 Size comparison of the NPRO (left) and the PW-ECL (right)

Figure 2 shows a comparison of its size with the non-planar ring oscillator (NPRO). The PW-ECL's package is much more compact than that of the NPRO, in which a strong magnet limits the size. We based our choice of the PW-ECL on an investigation of number of lasers [5].

Figure 3 shows the frequency noise of the 1064 nm (blue) and 1550 nm (black and red) PW-ECL, and Figure 4 shows the PW-ECL intensity noise in comparison to the NPRO. The frequency noise of the 1064 nm ECL must be lowered by a factor of 5 at 100 kHz so that cycle slips do not occur within the LISA phasemeter; this work is on-going at RIO. We have decided to build a space-qualified NPRO (already developed by several groups), in case the frequency noise requirement of the PW-ECL cannot be met. Figure 4 shows the PW-ECL intensity noise is significantly lower than the NPRO at frequencies around 1 MHz due to the presence of the NPRO relaxation oscillation.

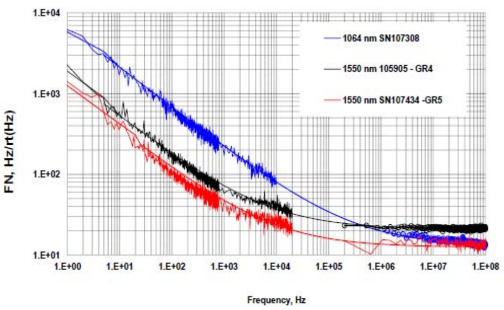

Fig. 3 Frequency noise of 1064, 1550 nm PW-ECLs

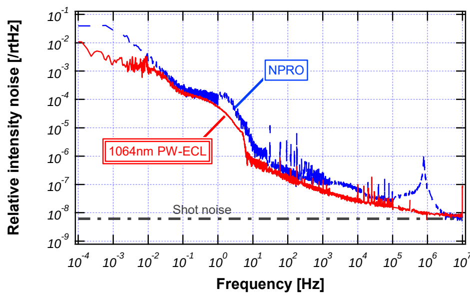

Fig. 4 Intensity noise of PW-ECL and NPRO

We made a detailed study of the mechanical, thermal, and radiation robustness of the PW-ECL, and found it to be qualified for use in space. Lucent Government Solutions (LGS) planned and oversaw the tests, which involved vacuum thermal cycling, hermiticity, radiation, and accelerated aging [6]. For these reasons, the 1550-nm PW-ECL was adopted as the metrology laser for the OpTIIX mission [7] on the International Space Station. We will revisit some of these reliability studies for the 1064 nm PW-ECL in FY17. We believe the risk of failing reliability testing is low, since it is using the same packaging as the 1550 nm PW-ECL and the 1064 nm gain-chip vendor (Eagleyard) data indicates high reliability.

3. Amplifier and Preamp Build

Our recently constructed 2.5 W fiber amplifier is shown in Fig. 5. It includes a pump diode to provide power, a tapered fiber bundle (TFB) to allow redundant power input, and a 2.3 m length, 10-µm core, double-clad, large-mode-area gain fiber that converts the pump power to amplification gain. The forward-pumped design and optical isolator minimize potential sources of feedback. The amplifier uses a robust mechanical design and temperature stabilization to suppress fiber-length variations. Its 2.5 W output power is shown in Fig. 6, along with a linearly-increasing backscattered power indicating negligible Stimulated Brillouin Scattering (SBS). The same package contains the PW-ECL as a maser oscillator, a SOA as a preamplifier, and a phase modulator, making it a complete opto-mechanical package of the LISA laser system. A clean output spectrum was observed with low Amplitude-Stimulated Emission (ASE) floor.

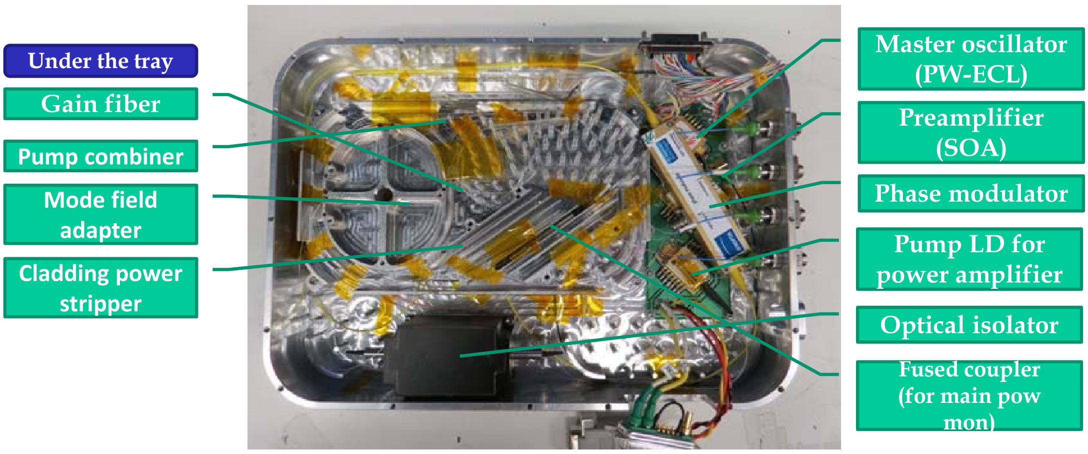

Fig. 5 Laser amplifier system including ECL, SOA preamp, phase modulator, gain fiber, and pump diode

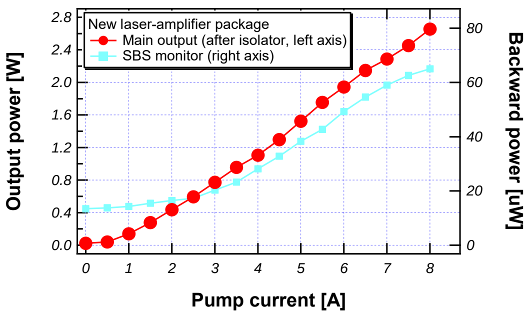

Fig. 6 Output of laser system, showing 2.5 W output power. No nonlinear increase in backward power indicates no sign of SBS buildup.

4. Laser System Noise Testing: We have performed laser system noise tests by amplitude- and frequency-stabilizing the PW-ECL and amplifier (Fig. 7). By stabilizing the amplifier pump-diode current, an amplitude noise attenuation of ~30 was achieved at a frequency of 0.1 mHz (a factor of ~10 from the LISA requirement). This noise will decrease once temperature stabilization of the amplifier and the detection system is applied. The laser system was also frequency-stabilized by locking a small fraction of the amplifier's output to a hyperfine absorption line of iodine molecule, using the PW-ECL's injection current as a frequency actuator. Fig. 8 shows that the differential phase noise of a 2 GHz sideband transmitted through the fiber amplifier meets the LISA requirements.

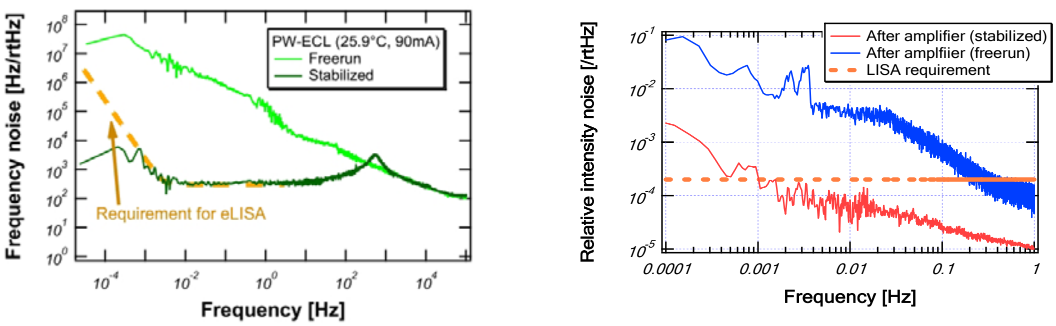

Fig. 7 Frequency and intensity noise of laser system: ECL, preamp and amplifier

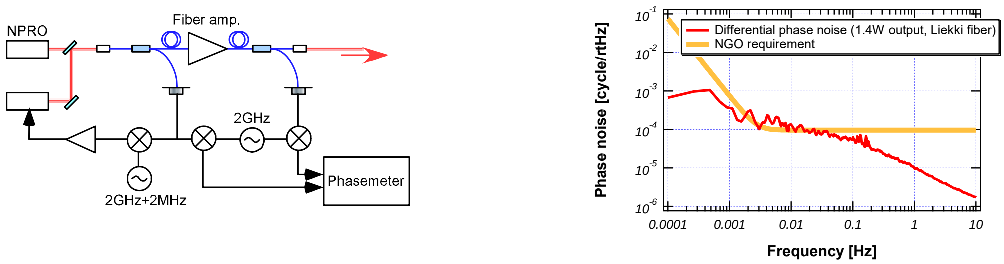

Fig. 8 Differential Phase Noise of the Laser System (right), determined with 2 GHz modulation frequency sidebands. The figure on the left shows the measurement apparatus

5. Laser Preamp Environmental Testing: a critical aspect of this work is environmental testing to prove flight readiness, which involves thermal vacuum cycling, vibration testing, and exposure to radiation levels that will be seen in the LISA space environment. These tests have been applied to the PW-ECL oscillator and a fiber preamp, as shown below. The fiber preamp (Fig. 9) contained a Yb doped gain fiber of 2 m length, and key components including optical isolator, polarization combiner, wavelength multiplexer, pump diodes, and fiber splices.

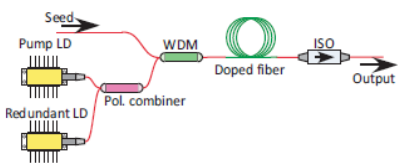

Fig. 9 Fiber preamplifier

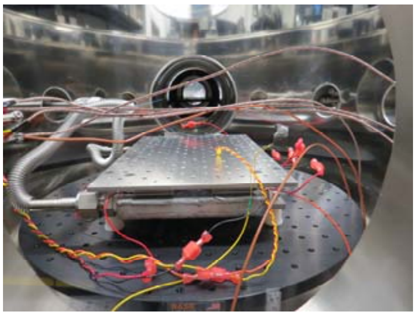

Fig. 10 Thermal vacuum cycling apparatus

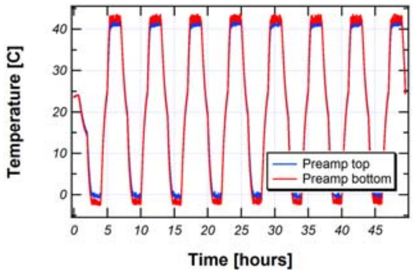

Fig. 11 Thermal levels in preamp/PW-ECL

Fig. 10 shows the vacuum cycling apparatus deployed in our laser lab, and Figure 11 shows the thermal levels and duration used in the thermal cycling of the preamp. Fig. 12 shows the vibration ("shaker") apparatus used to vibrate the preamplifier and other components under test, while figure 13 shows the acceleration time-series that the shaker provides.

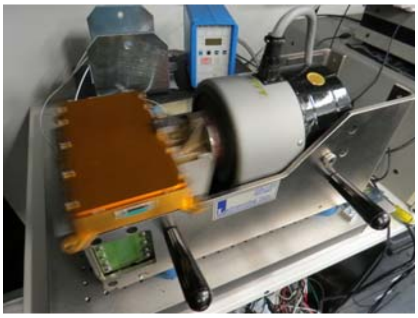

Fig. 12 vibration instrument shaking preamp/ECL

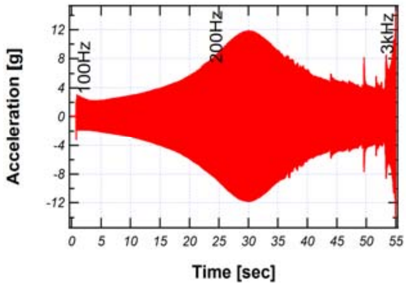

Fig. 13 acceleration from vibration apparatus

The results of the preamp environmental testing are shown in Fig. 14. There was no effect on the output power from thermal cycling or vibration. There was a ~30% drop in output power from gamma-ray radiation exposure, with exposure at the full LISA level of 45 krad in 8 hours, which represents a rate 10^4 times the LISA rate experienced in a 5 year orbit. Since radiation damage is related to the both the total exposure and the rate, another run with higher exposure is needed to separate the two effects and determine whether radiation shielding should be considered.

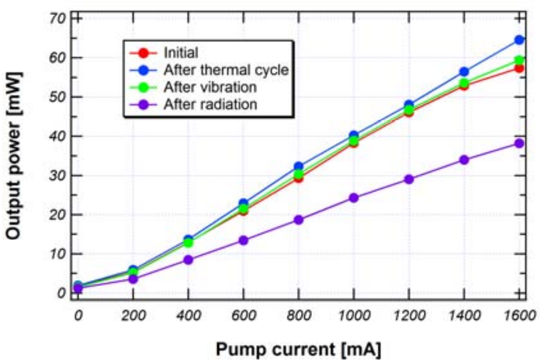

Fig. 14 Results of environmental testing on ECL + preamp

The environmental testing facility will be used in the future to test the full laser system, with the thermal cycling temperature range and the acceleration levels tuned to match the LISA mission launch parameters.

6. Future Plans

Remaining work on the US laser system for LISA includes: 1) reduction of the 1064 nm PW-ECL frequency noise, which will involve a redesign of the gain chip to address thermal issues that are causing ellipticity in the laser beam; 2) design and construction of a space-qualified NPRO as a backup oscillator option; 3) reliability testing of individual laser system components to show compliance with a 5 year lifetime requirement; 4) accelerated aging and reliability testing of the full laser system to demonstrate the 5 year lifetime requirement is met. Tasks 1) and 2) can be carried out in parallel. After the final oscillator is downselected Task 3) will be done, followed by Task 4) which will demonstrate TRL 5.

The above tasks are achievable by 2020 provided sufficient funding to the laser system development is allocated. Another possibility may be a funding level consistent with delivery of a TRL 5 laser system by 2024. Importantly, NASA has recently received input from the 2016 Mid Decadal Review [8] emphasizing the need for increased US technology funding to allow the Agency to play an important role in LISA.

7. Summary

NASA/GSFC has been involved in research on spaceborne lasers since the 1990s. Taking advantage of its space laser experience and the emerging telecom laser technology, we are developing a full laser system for the LISA mission. Our research has included both master laser and amplifier developments, and their environmental testing and reliability for space flight. We are awaiting decisions on funding that will allow us to deliver a TRL 5 laser system in the 2020-2024 timeframe.

References

[1] Abbott B et al (LIGO Scientific Collaboration and Virgo Scientific Collaboration), PRL **116** 061102 (2016)
[2] Armano M et al, PRL **116** 231101 (2016)
[3] Numata K and Camp J 2012 *Laser Phys. Lett.* **9** 575
[4] Koren U et al, *Applied Phys Lett* **53**, 2132-2134
[5] Numata K, Camp J, Krainak M A and Stolpner L 2010 *Opt. Express* **18** 22781
[6] Numata K and Camp J 2012 *J. Phys.: Conf. Ser.* **363** 012054
[7] Postman M, Sparks W B, Liu F, Ess K, Green J, Carpenter K G, Thronson H and Goullioud R, 2012 *Proc. SPIE* **8442** 84421T
[8] www.nap.edu/catalog/23560/new-worlds-new-horizons-a-midterm-assessment